# Intel® Thermal Analysis Tool (TAT)

## User Guide

***September 2005***

***Revision 2.0***

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# Revision History

| Rev. # | Document Number | Date | Reason for Changes |
|---|---|---|---|
| 2.0 BETA 2 | | June 12 2005 | Revised 1.7 → 2.0 BETA 2 (Single → Dual Core Processors) |
| 2.0 RC | | July 31, 2005 | Updated the version number from 2.0 BETA 2 → 2.0 RC |
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| 2.0 Gold | | September 20, 2005 | Updated the version number from 2.0 RC 2 → 2.0 Gold |



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# 1 Overview

The Intel® Thermal Analysis Tool (TAT) provides capabilities to analyze an OEM's thermal design. Features include the ability to stress CPU, monitor CPU temperature, reduce CPU frequency, Monitor CPU throttle activity and log CPU activity to a file.

**Table 1. Terminology**

| Term | Definition |
|---|---|
| TAT | Thermal Analysis Tool |
| DDR II | Double Data Rate |
| OEM | Original Equipment Manufacturer |
| MCH | Memory Controller Hub (also referred to as chipset) |
| $T_{sys}$ | System temperature effect on CPU |
| $T_{die}$ | Temperature of the die surface at center measured by a thermocouple |
| $T_{junction}$ | Temperature of the CPU from the internal temperature sensor |
| Prochot# | See Intel Thermal Monitor in section 5.2 |
| TC | Thermocouple |



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# 2 Hardware Requirements

The *Intel®* Thermal Analysis Tool (TAT) is designed to operate on systems utilizing Intel® brand mobile chipsets and Intel® Mobile brand processors.

Specifically version 2.0 is intended to be used on the Napa platform moving forward. It will not be backward compatible with previous generation platforms.

To make use of the temperature monitoring feature the sensor in the processor must be accessible by the BIOS and the ACPI thermal zones must be implemented in the Operating system.



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# 3 Environmental Requirements

During testing the notebook system should be placed in a still-air environment where it is isolated from any sources of air currents such as Heating, Ventilating and Air Conditioning (HVAC) vents. Ideally, an environmental chamber should be used to isolate the system and test under elevated ambient temperatures based on OEM design specifications. Ambient design specification for notebooks is typically 35°C.

When using an environmental chamber, place a thick wooden surface underneath the notebook to simulate conditions on a tabletop similar to the setup shown in Figure 1. If these conditions are not met the test will yield measured temperatures that could be lower than what would be expected under typical operating conditions. This will lead to over estimating the thermal limit of the chipset.

Most environmental chambers include a re-circulation system with fans that try to maintain an even distribution of temperature within the chamber. The re-circulation fans should only be used prior to testing while preheating the chamber to the setpoint temperature. Once the chamber has been preheated to a setpoint temperature the fans should be turned off, otherwise the circulation of air within the chamber will increase the amount of convective cooling around the notebook and this will not be representative of typical operating conditions. At this point if the oven temperature continues to rise adjust an opening to the chamber to compensate for the ambient rise. This should have minimal effects on air currents.

If testing in an environmental chamber is not feasible the testing may be conducted at room temperature with the assumption that all of the temperature measurements need to be scaled up to the ambient design specification. For example, if the temperature data is gathered at a room temperature of 22ºC and the ambient design specification is 35ºC, the difference between the two temperatures (13ºC) should be added to all of the measurements. Scaling data from a lower ambient is not enough to ensure functionality at 35°C. It is still recommended to conduct testing at 35°C.

**Figure 1. Notebook in Environmental Chamber**

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# 4 Software Requirements

To run the Intel Thermal Analysis Tool, you will need to run under Windows* XP. To install the software, simply run the Self-Extracting EXE file obtained from your Intel support representative. The system must be re-booted before running the software for the first time. At this point you may run the application from Start/All Programs/Intel® Thermal Analysis Tool/Thermal Analysis Tool.

To remove the software, use the uninstall feature provided with Windows XP. Go to the *Control Panel -> Add/Remove Programs -> Thermal Analysis Tool.* Go through this un-installation process to ensure that all components are properly removed from the operating system.



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# 5 Software Features

## 5.1 Thermal Sensor Monitor

The Intel® mobile processor line, specifically Yonah processor, incorporates three methods of monitoring die temperature, the Intel Thermal Monitor, two Digital Thermal sensors and the Thermal diode. The Intel Thermal Monitor (discussed in Section 5.3) must be used to determine when the maximum specified processor junction temperature has been reached. The second method is to use the two digital thermal sensors for thermal management. These should be used as the main method of thermal management as the locations are in each core. The third method, the thermal diode, may be used to monitor the die temperature of the processor for thermal management or instrumentation purposes but cannot be used to indicate that the maximum Tj of the processor has been reached. This method should be used as a backup to DTS. (Contact your FAE for the most up to date processor information in the EMTS)

### 5.1.1 Digital Thermal Sensor Reading

The Intel® Yonah processor has two digital thermal sensors. 1 is placed in the hotspot of each core. TAT has the ability to monitor these two DTS locations either directly through the MSR bits or through ACPI if being reported.

### 5.1.2 Thermal Diode Reading

TAT monitors the Thermal Diode in the CPU. This is done by monitoring the ACPI Thermal Zone for the CPU. If CPU Diode is enabled using other methods, TAT will not be able to monitor this. The location of the diode for Yonah has been moved. It is now in-between the two cores. Previously in Pentium-M™ it was located near the hotspot.

**Note:** The reading of the external thermal sensor (on the motherboard) connected to the processor thermal diode signals, will not necessarily reflect the temperature of the hottest location on the die. This is due to inaccuracies in the external thermal sensor, on-die temperature gradients between the location of the thermal diode and the hottest location on the die, and time based variations in the die temperature measurement. Time based variations can occur when the sampling rate of the thermal diode (by the thermal sensor) is slower than the rate at which the Tj temperature can change.

### 5.1.3 Thermal Monitor (Prochot# / TCC Trigger)

The Intel Thermal Monitor helps control the processor temperature by activating the TCC when the processor silicon reaches its maximum operating temperature. The temperature at which Intel Thermal Monitor activates the thermal control circuit (TCC) is not user configurable and is not software visible.

The Intel Thermal Monitor controls the processor temperature by modulating (starting and stopping) the processor core clocks or by initiating an Enhanced Intel SpeedStep technology transition when the processor silicon reaches its maximum operating temperature. The Intel



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Thermal Monitor uses two modes to activate the TCC: Automatic mode and On-Demand mode. If both modes are activated, Automatic mode takes precedence.

TAT monitors an MSR bit for Thermal Monitor Activity. There is a window for each core that states Thermal Monitor Idle or Active.

**Caution:** The Intel Thermal Monitor Automatic Mode must be enabled via BIOS for the processor to be operating within specifications.

## 5.2 Frequency Monitor

Displays Current Operating Frequency on each core for the Yonah processor

## 5.3 On Demand Throttling

On Demand throttling reduces the processor frequency by MSR bits (Default) or by Chipset (Advanced Preferences), in 12.5% decrements. 0% = full frequency. This can be done on each Yonah core separately for CPU option. If Chipset option is chosen then both cores will throttle at the same time.

Note: Because of overhead associated with throttling in each method the reported frequency should be correct. Calculating the % of frequency would be incorrect.

## 5.4 Workload Stress Options

This option is based on a stress algorithm that is the highest known workload for the processor (100%). We have tuned several percentages below this to allow for some strategic thermal testing. One key workload is the Thermal Design Power. TDP achieves a sustainable workload similar to a high powered sustained peak from an off the shelf application. This TDP value has yet to be determined and will be implemented in the final version of TAT.

## 5.5 Results Window

The window displays all current activity.

- Processor Cstate transitions
- Thermal Diode / DTS changes
- On Demand frequency changes
- Throttle activity

Start / Stop Monitor

## 5.6 Logging Options

The following have editable target locations in Options→Output Preferences



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- Log to a file
    - CPU Frequency
    - DTS values
    - ACPI values
- Output Results
    - Sends all current day in the Results window to a text file

## 5.7 OSPM Settings / Config

### The Following is From Chapter 12 in the ACPI 2.0c SPEC available at www.acpi.info

**OSPM**

- Operating System Directed Configuration and Power Management

**Thermal Zones**

- Thermal States
  Thermal states represent different operating environment temperatures within thermal zones of a system. A system can have one or more **thermal zones**; each thermal zone is the volume of space around a particular temperature-sensing device. The transitions from one thermal state to another are marked by trip points, which are implemented to generate an SCI when the temperature in a **thermal zone** moves above or below the trip point temperature.

**_CRT**

- Critical Trip Point
- Thermal zone object that returns critical trip point in tenths of a degree Kelvin
- Note in TAT this is converted to Celsius

**_TZP**

- Thermal zone polling frequency in tenths of a second

**SCI**

- Temperature change events

**_TC1**

- Thermal zone object that contains thermal constant for Passive cooling.

**_TC2**

- Thermal zone object that contains thermal constant for Passive cooling.

**_TMP**

- Thermal zone object that returns current temperature in tenths of degrees Kelvin. Note in TAT we convert this to Celsius.

**_PSL**

- Thermal zone object that returns list of passive cooling device objects.

**_TSP**

- Thermal zone object that contains thermal sampling period for Passive cooling.

**_PSV**

- Thermal zone object that returns Passive trip point in tenths of degrees Kelvin. Note in TAT we convert this to Celsius.

**_Alx**

- Thermal zone object containing a list of cooling device objects.



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**The Following is From SYSTEM_POWER_POLICY on** http://msdn.microsoft.com/library/default.asp?url=/library/en-us/power/base/system_power_policy_str.asp **on MSDN**

**FanThrottleTolerance**

- Lower limit that the processor may be throttled down to prior to turning on system fans in response to a thermal event, expressed as a percentage.

**ForcedThrottle**

- Processor throttle level to be imposed by the system, expressed as a percentage.

**DynamicThrottle**

- Processor throttle level to be imposed by the system, expressed as a percentage.

**The Following is From the Performance Control Policy Constants at** http://msdn.microsoft.com/library/default.asp?url=/library/en-us/power/base/processor_performance_control_policy_constants.asp **on MSDN**

**PO_THROTTLE_ADAPTIVE**
Attempts to match the performance of the processor to the current demand. This policy will use both high and low voltage and frequency states. This policy will lower the performance of the processor to the lowest voltage available whenever there is insufficient demand to justify a higher voltage. This policy will engage processor clock throttling if the C3 state is not being utilized, and in response to thermal events.

**PO_THROTTLE_CONSTANT**
Does not allow the processor to use any high voltage performance states. This policy will not engage processor clock throttling, except in response to thermal events.

**PO_THROTTLE_DEGRADE**
Does not allow the processor to use any high voltage performance states. This policy will engage processor clock throttling when the battery is below a certain threshold, if the C3 state is not being utilized, or in response to thermal events.

**PO_THROTTLE_NONE**
No processor performance control is applied. This policy always runs the processor at its highest possible performance level. This policy will not engage processor clock throttling, except in response to thermal events.

Pasted from <http://msdn.microsoft.com/library/en-us/power/base/processor_performance_control_policy_constants.asp?frame=true>



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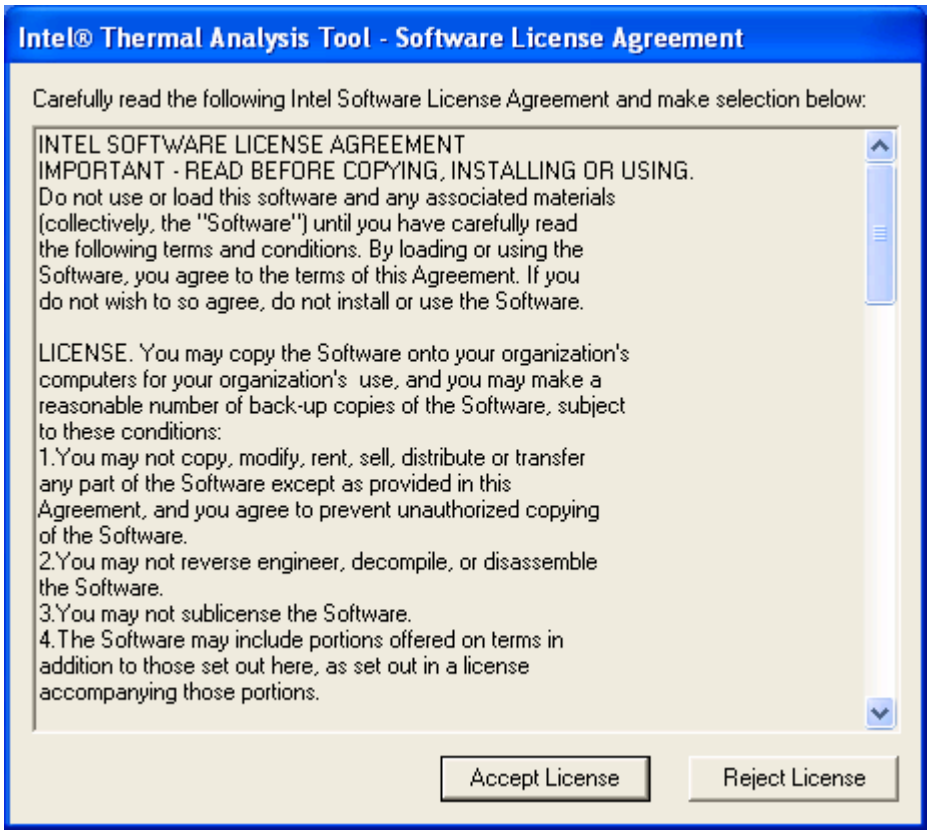
# 6 Software Operation

The Intel Thermal Analysis Tool Application is provided with an easy to use user interface that runs on a Windows XP operating system. Before running the software make sure that all of the hardware and environmental requirements have been met.

1. Ensure that all other applications have been closed before running the Thermal Analysis Tool Application. Execute the program by running the shortcut *Start Menu* -> All Programs -> *Intel® Thermal Analysis Tool -> Thermal Analysis Tool*
2. The program starts with a disclaimer screen.
   a. You must accept the agreement before using TAT for the first time.

**Figure 2: TAT Disclaimer**


Intel® Thermal Analysis Tool - Software License Agreement
Carefully read the following Intel Software License Agreement and make selection below:
INTEL SOFTWARE LICENSE AGREEMENT
IMPORTANT - READ BEFORE COPYING, INSTALLING OR USING.
Do not use or load this software and any associated materials
(collectively, the "Software") until you have carefully read
the following terms and conditions. By loading or using the
Software, you agree to the terms of this Agreement. If you
do not wish to so agree, do not install or use the Software.
LICENSE. You may copy the Software onto your organization's
computers for your organization's use, and you may make a
reasonable number of back-up copies of the Software, subject
to these conditions:
1.You may not copy, modify, rent, sell, distribute or transfer
any part of the Software except as provided in this
Agreement, and you agree to prevent unauthorized copying
of the Software.
2.You may not reverse engineer, decompile, or disassemble
the Software.
3.You may not sublicense the Software.
4.The Software may include portions offered on terms in
addition to those set out here, as set out in a license
accompanying those portions.
Accept License
Reject License

3. The following is a sample of the default user interface



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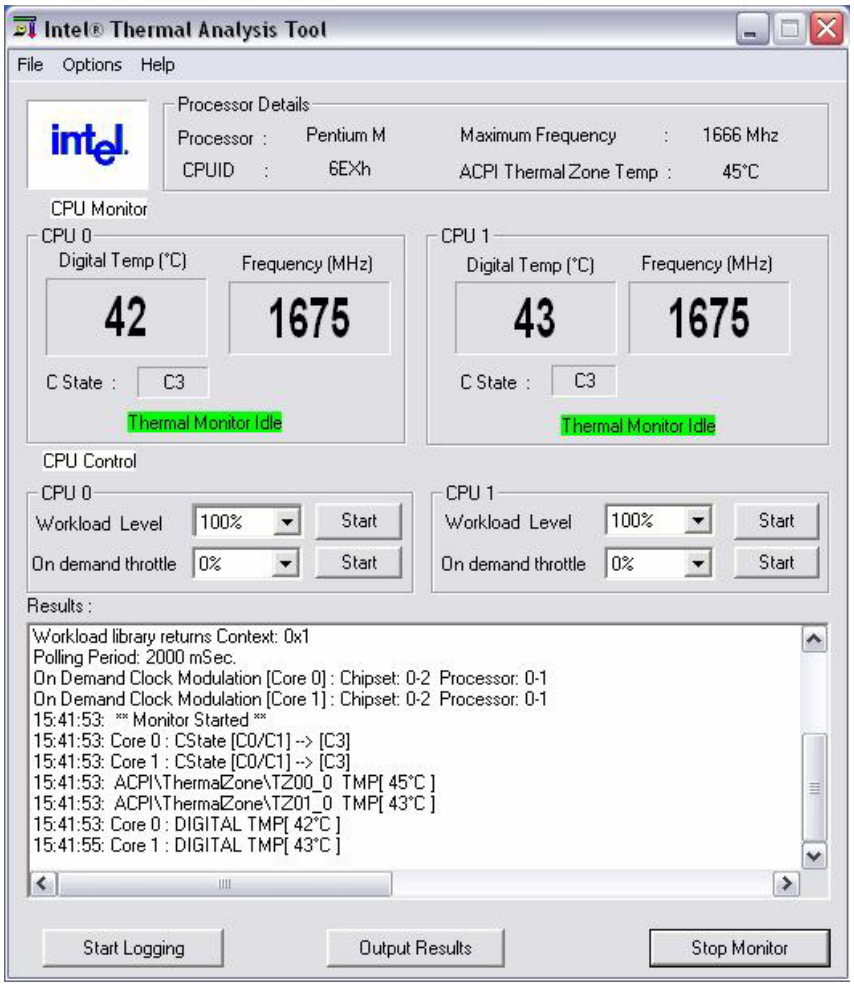
**Figure 3: TAT GUI**




4. It is possible to run multiple workload tests unattended. This option, “workload test” can be selected in the advanced preferences. You must also set a time for this feature. This will determine how long each workload will run. If you set 1 hour then when you run this test each selected workload will run for 1 hour.



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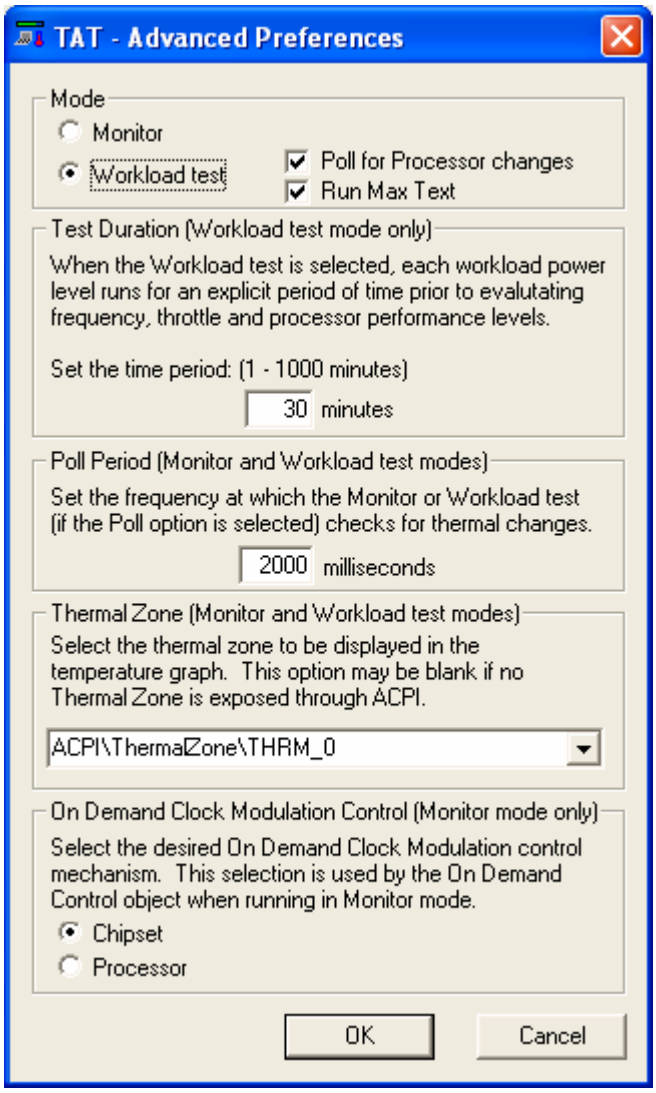
**Figure 4: TAT Advanced**


TAT - Advanced Preferences
Mode
Monitor
Workload test
Poll for Processor changes
Run Max Text
Test Duration (Workload test mode only)
When the Workload test is selected, each workload power level runs for an explicit period of time prior to evalutating frequency, throttle and processor performance levels.
Set the time period: (1 - 1000 minutes)
30 minutes
Poll Period (Monitor and Workload test modes)
Set the frequency at which the Monitor or Workload test (if the Poll option is selected) checks for thermal changes.
2000 milliseconds
Thermal Zone (Monitor and Workload test modes)
Select the thermal zone to be displayed in the temperature graph. This option may be blank if no Thermal Zone is exposed through ACPI.
ACPI\ThermalZone\THRM_0
On Demand Clock Modulation Control (Monitor mode only)
Select the desired On Demand Clock Modulation control mechanism. This selection is used by the On Demand Control object when running in Monitor mode.
Chipset
Processor
OK
Cancel

This brings up the following user interface:

Now when you hit “Start Test” you have the option to choose which workloads will be run.



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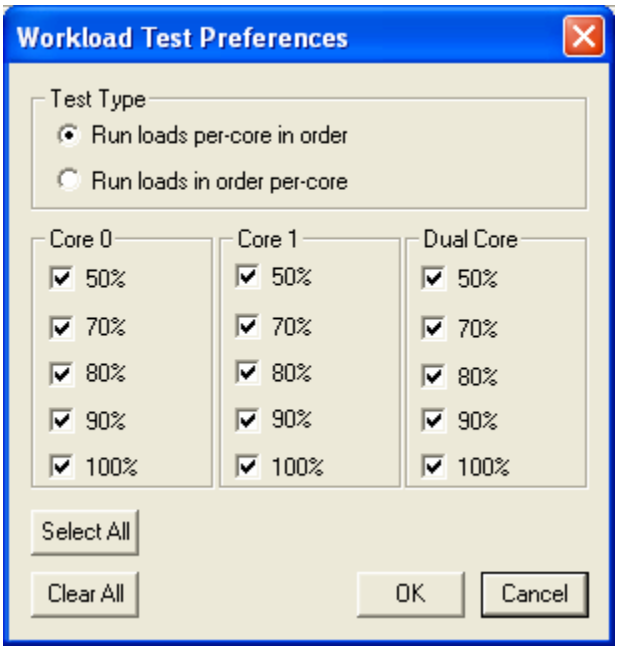
**Figure 5: TAT Workload Options**




When you hit OK the selected workloads will run from lowest to highest with the exception of TDP which gets run last. Each workload will run for the amount of time set in the advanced preferences.



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# 7 Sample Data Collection Process

## 7.1 Thermal Testing Using TAT

$T_{system}$ in the thermal resistance calculation is the additional temperature of the processor due to additional heat that the remainder of the system adds to the thermal resistance. In a notebook environment, components are affected by other heat generating devices in the system. This effect is denoted as $T_{system}$ and is represented by the increase in junction temperature due to the heating affects of other components in the system. Failure to measure $T_{system}$ can result in either overestimating or underestimating the system capability. Both instances will produce problems with thermal capability evaluation. If $T_{system}$ is understimated, then the system may throttle unexpectedly. If $T_{system}$ is overestimated, then higher speed processors could have been installed, thus the life of the system would be unduly shortened.

Measurement of $T_{system}$ for a system requires thermal analysis tool or another application that can maintain a single power load. It would be preferable to use an application that stresses multiple components with in the system as Tsys will vary based on how much and how many components are stressed.

- Run the workload level at 100% and throttle set to 50%. Let the system temperatures stabilize (less than half a degree change in half an hour).
- At the end of the test, record the diode, heat pipe beginning, ambient temperatures, and processor power.
- Repeat the above mentioned test at the same power level of 100% and change On-Demand Throttle settings to 37.5%, 25%, 12.5%, and 0%. This will ensure that the internal ambient temperatures are not erroneously high.
- There may be a 2°C to 5°C offset that can be assumed or perform a system testing in controlled environment (thermal chamber).
- The processor diode and ambient temperatures should be pulled from each stabilization point (Figure 3). The delta between diode and ambient temperatures and processor power should then be plotted as in (Figure 4). Collecting temperature and power values at five different throttle levels will help in minimizing error in t-sys value calculation.



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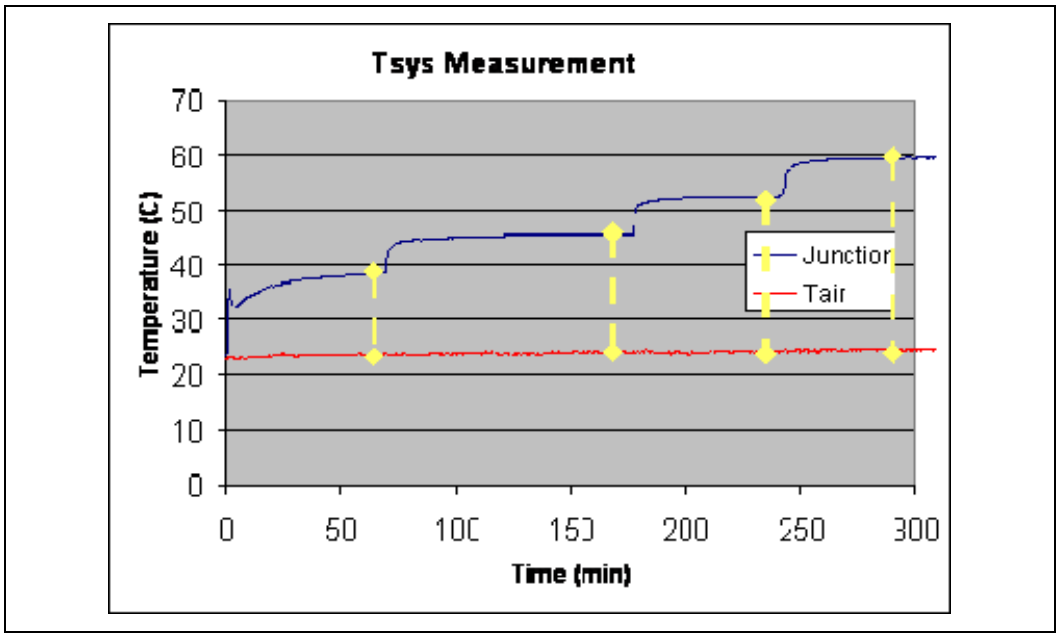
**Figure 6. Stabilized Temperature Measurement Example**



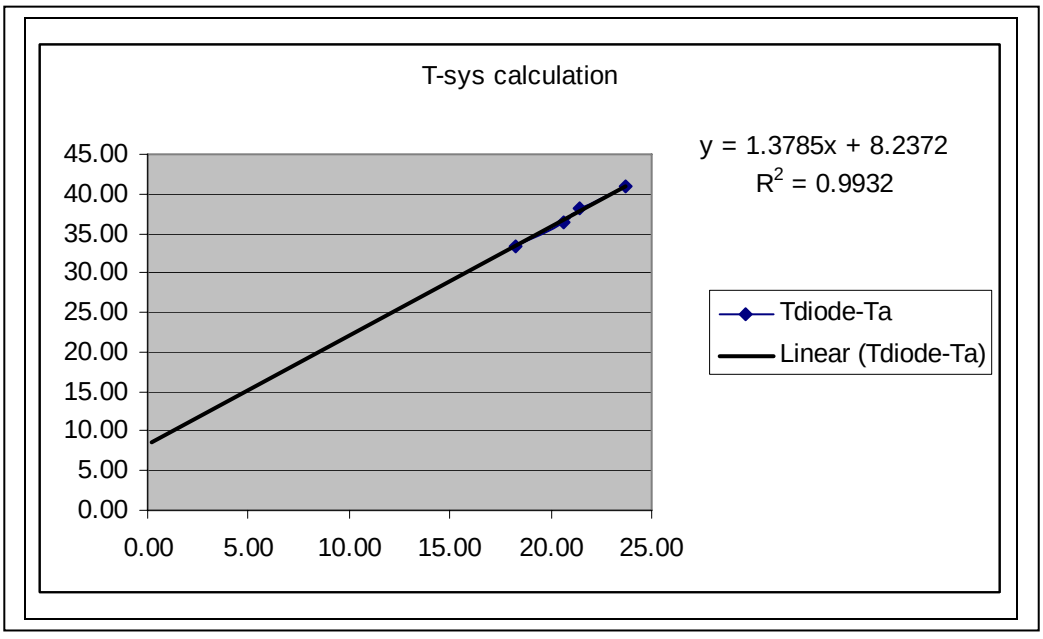




**Figure 7. Graph For T-sys Calculation**

A trend line through the data points will reveal a linear fit **y = mx + b** where the slope (m) is the thermal resistance of the system ($\theta_{j\text{-}a}$) and the y-intercept is the measured system effect ($T_{system}$).



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## 7.2 Verifying TDP

TDP is defined in the following two ways.

- Thermal Design Power Application Ratio (TDP AR)
- Thermal Design Power (TDP)

Typical Design Power Application Ratio is what TAT uses to define its TDP workload option. This value is a ratio of worst case synthetic workload and worst case sustained off the shelf application peak power.

- The power draw achieved will vary slightly from part to part due to high or low leakage.

Typical Design Power is the power achieved by a worst case part running the TDP AR. Most CPU parts will achieve a power below the TDP value.

- This is more of an estimate of what CPU power will be when it gets closer to the end of the CPU manufacturing process life cycle. Or as the processor frequency is increased over time, it will be able to achieve TDP AR values closer to the TDP.

### 7.2.1 How to check if your system can maintain the TDP workload and stay within thermal Specification

1. Setup your system to run TAT in the environmental conditions specified in Section 3.
2. Choose the TDP workload in TAT and start the workload.
3. Monitor CPU diode temperature until stable.
4. Make note if any throttle activity is recorded in the results window.

If there is no throttle activity and your processor temperature remained below the thermal specification your system can maintain the TDP workload and should be able to handle most off the shelf application without going over spec.

Note: It is difficult to test for all possible applications on the market. There may be an application that draws more power from the CPU than the TDP workload in TAT. This should be taken into consideration if you are on the board of the thermal specification. If this is the case improvements to your thermal solution are recommended.



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